EVALUATING THE IMPACT OF ETHEPHON ON BUD BREAK AND DELAYED PRUNING ON CLUSTER COUNT IN WINEGRAPES

A Thesis

by

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ABSTRACT

Grapes are an important crop in the United States with most of their value towards winegrapes. Frost and freeze events are a major weather-related problem, and late spring freeze/frost can cause considerable yield loss for growers, thus affecting the wine industry. Although there are numerous methods of frost protection, many are impractical or are not very effective.

This project focused on the use of ethephon as a tool to prevent late spring frost damage by delaying bud break in grapes, and the impact of delayed pruning on vine fruitfulness (cluster count).

Ethephon treatments consisted of applying ethephon as a spray on dormant canes at a rate of 145 mg L^{-1} (low) and 291 mg L^{-1} (high) at five different timings: November, December, January, February, and March. The greatest delay in bud break was observed in vines treated with ethephon in January. The high rate was more effective than the low rate and highly dependent on cultivar, except for low rate applications in November which showed adverse effects by advancing bud break during the spring. The results of this study suggest that the use of ethephon as a tool to delay bud break requires further research before it can be recommended.

In the delayed pruning study, eight cultivars and numbered selections were subjected to final pruning at 50% bud break and final pruning at 3 weeks after 50% bud break. Across the six cultivars and numbered selections under study, a 19-80% decrease in cluster count was observed. However, vine vigor as determined by shoot length and

shoot diameter was not significantly influenced by the delayed pruning treatments. These results suggest that pruning three weeks after bud break can be detrimental to grape yield and is not recommended as a means to avoid or mitigate late spring frost damage.

DEDICATION

This thesis is dedicated to some special people in my life, and I would like to thank them for all of their support, patience and understanding during this chapter of my education. The completion of this degree would not been possible if it wasn't for them.

Husband: Andrew J. Labay

Mother: Rosa H. Garcia

In-laws: Kathleen and Steve McCombs

Friends: Karin M. and Russell Wallace

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Contributors

This thesis work was overseen by a committee consisting of Dr. Justin J. Scheiner as committee chair, Dr. Leonardo Lombardini as committee member from the Department of Horticulture and Dr. David N. Appel as committee member from the Department of Plant Pathology and Microbiology.

Data analysis for this project was conducted in collaboration with Andrew J. Labay and under the guidance of Dr. Scheiner from the Department of Horticultural Sciences. All other work was completed by the student, under the guidance of Dr. Scheiner.

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NOMENCLATURE

1103P	Paulsen 1103
5BB	Kober 5BB
ABA	Abscisic Acid
kPa	Kilopascal
m/s	Meter per Second

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CHAPTER I

INTRODUCTION

Grapes are the highest value fruit crop in the United States followed by oranges and apples (USDA-NASS, 2015). In 2014, the USDA-NASS (USDA-NASS, 2015) reported a total annual production of 7,771,830 tons, of which 4,522,320 ton were used for wine production, a total of 1,049,600 bearing acres, and a value above $5.8 billion. Despite this success, there are many challenges to grape production and frost/freeze damage has been identified as the most significant weather-related problem for growers (Snyder & De Melo-Abreu, 2005).

The Texas winegrape industry has grown significantly in the past 10 to 15 years. The census of agriculture reported more than 7,000 acres of grapes planted in Texas (USDA-NASS, 2012). As of January 2018, 450 wineries have been issued a permit by the Texas Alcoholic Beverage Commission, and the industry is currently estimated to contribute more than $13.1 billion to Texas economy (Texas Wine and Grape Growers Association 2017).

Commercially important cultivars to the United States include, Cabernet Sauvignon, Cabernet Franc, Merlot, etc., which are *Vitis vinifera* grapes of European origin (Schultze et al., 2016). Due to differences amongst American and European climates during the growing season, *vinifera* cultivars have come across many challenges in the United States including weather related damages (Schultze et al., 2016).

The grape and wine industry in Texas has been troubled with late spring freeze events that damage or kill young shoots after bud break. Young shoot tissue is highly vulnerable to freezing temperatures (Johnson & Howell, 1981; Snyder & De Melo-Abreu, 2005; Friend et al., 2011; Filho et al., 2014), and late spring freeze injury can result in a reduction of crop yield due to the loss of primary bud shoots (Snyder & De Melo-Abreu, 2005; Friend et al., 2011; Molitor et al., 2014; Frioni et al., 2017). The primary bud is the most physiologically developed bud with respect to inflorescence primordia (Williams, 2000; Vasconcelos et al., 2009). Compound buds on grape shoots also contain secondary and tertiary buds that are less fruitful in most *Vitis vinifera* cultivars.

Research reports have shown that up to two-thirds of the fruit yield is lost when primary shoots are killed by late spring freeze and secondary shoots emerge (Friend et al., 2011). Spring frost damage effects on reduction of fruit quality is not fully known, although some research has shown that fruit quality remains similar with only a few differences in cluster composition (Filho et al., 2014; Frioni et al., 2017). Some researchers predict that these events will be more frequent in the future as a result of climate change because plants will break bud earlier due to warmer winter temperatures (Poling, 2008; Molitor et al., 2014; Kartschall et al., 2015).

CHAPTER II

EVALUATING THE IMPACT OF ETHEPHON ON BUD BREAK IN WINEGRAPES

2.1. Introduction and literature review

2.1.1. Current methods of protection

There are multiple methods for protecting against late spring frost/freeze events. Protective or active methods are direct frost protection methods that require significant amounts of energy/labor before and/or during a freeze event. Several active methods include heaters (e.g. propane/fuel heater and brush burning), wind machines (e.g. conventional or vertical flow wind machines, and helicopters), sprinklers (e.g. over or under-plant sprinklers, microsprinklers, heated water, and targeted sprinklers), and foggers (Snyder & De Melo-Abreu, 2005; Poling, 2008). Preventive or passive methods are indirect frost protection methods that do not involve intensive energy/labor and are executed before a freeze event. Passive methods consist of site selection, cultivar selection, pruning (e.g., double/delayed), site management (e.g., fertilization, disease control) and bud break delay (e.g., cooling or chemical) to avoid exposing susceptible tissue to frost events (Snyder & De Melo-Abreu, 2005; Poling, 2008; Centinari et al., 2016).

2.1.2. Practicality of current methods

Although there are several methods available to aid in mitigating late spring frost damage, many are impractical due to high cost, high labor/energy requirements, low effectiveness, and secondary damages (Snyder & De Melo-Abreu, 2005; Poling, 2008). For instance, ground-based, upward blowing wind machines can have little to no benefit, while conventional, horizontal wind machines have shown more benefits but are more expensive (Battany, 2012). The use of cryoprotectants (anti-freeze effects) has shown minimal to promising results but these have not been consistent, thus suggesting that cultivar selection is a better option (Himelrick et al., 1991; Centinari et al., 2016). Overhead sprinklers are considered the highest level of protection but may be impractical due to the high water usage per event, and when used incorrectly, may cause significant damage to the crop (Poling, 2008). Much of these methods of frost protection are dependent of many factors such as duration of the event, wind speed, temperature inversions, vine development stage, and terrain (Snyder & De Melo-Abreu, 2005; Poling, 2008). Furthermore, the type of frost event can have a significant impact on the approach. Frost events can be defined as advective or radiation. An advective frost is a combination of cold air, windy conditions, and subzero temperatures (measured in Fahrenheit degrees). A radiation frost consists of temperature inversion on clear calm night and plant cooling through energy loss (Snyder & De Melo-Abreu, 2005).

2.1.3. Ethylene

Ethylene is a simple gaseous hydrocarbon with chemical formula C_2H_4. Ethylene is a plant hormone which is involved in many plant development processes (Davies, 1995; Rademacher, 2015) such as: seed germination, shoot elongation, epinasty, fruit maturation, fruit and leaf abscission, post-harvest fruit ripening, and dormancy (Abeles et al., 1992; Davies, 1995; Kanellis et al., 2012; Rademacher, 2015). Ethylene was the first chemically identified plant growth and development regulator (Bleecker, 1999).

Research in ethylene use for leaf abscission reports that abscission is influenced by accelerating senescence (Burg, 1968; Jackson & Osborne, 1970). Leaf age is important when applying ethylene for abscission, as leaves mature less ethylene gas is required to show defoliation effects (Burg, 1968). Old leaves ease to abscise is correlated to their lower levels of auxin, in comparison to young leaves that contain higher levels of auxin which requires higher amounts of ethylene to cause defoliation (Burg, 1968). However, if auxin levels remain higher after ethylene application, epinasty occurs in place of defoliation (Burg, 1968).

Ethylene production can occur in almost any part on the plant: seeds, roots, stems, leaves, flowers, and fruits (Davies, 1995). From these different plant tissues ethylene is synthesized from methionine to S-adenoxyl-L-methionine by a Met Adenosyltransferase enzyme. S-adenoxyl-L-methionine is then converted to l-aminocyclopropane-l-carboxylic acid (ACC) by an ACC synthase enzyme. Lastly ACC is converted to ethylene by ACC oxidase. l-aminocyclopropane-l-carboxylic acid

synthase is an important intermediate as it determines the ethylene production rate (Adams & Yang, 1979; Davies, 1995).

2.1.4. Ethephon

Ethephon [(2-chloroethyl) phosphonic acid, chemical formula $C_2H_6ClO_3P$) is an ethylene-producing compound which is highly soluble in water, labeled as a corrosive product, and has shown to have low toxicity levels to the environment (Szyjewicz et al., 1984; Goudey et al., 1987; Davies, 1995). Ethephon is widely used on agricultural crops, for its ethylene release ability, as a plant growth regulator (Biddle et al., 1976). Maynard & Swan (1963) found that ethephon decomposes into ethylene, chloride and phosphate at pH 4.5 and higher, while it remains stable at lower pH. Research on the decomposition rate of ethephon showed results of rapid breakdown into ethylene as pH value increased from 6 to 8, whereas temperature increase did not show significant decomposition rate between 25 and 50 °C (Biddle et al., 1976).

Additional research also showed that ethephon promotes abscisic acid (ABA) and inhibits growth (Mannini & Ryugo, 1982; Hansen & Grossmann, 2000). Abscisic acid is a plant hormone known as a growth inhibitor. It is involved in dormancy and stress responses (Abeles et al., 1992; Anderson & Seeley, 1993; Hansen & Grossmann, 2000). Ethephon promotes ABA levels through ethylene-induction (Mannini & Ryugo, 1982; Hansen & Grossmann, 2000). Auxin induced ethylene increases ABA levels through stimulation of epoxy-carotenoids to xanthoxal (Hansen & Grossmann, 2000).

Ethephon has been used extensively on stone fruit for bloom delay to overcome late spring freeze damage (Moghadam & Mokhtarian, 2006). Currently, ethephon is not

labeled for delaying bud break in grapes; however, it may be used as a spray during veraison to aid in the maturation process of berries (El-Banna & Weaver, 1979; Shulman et al., 1985).

In peaches, ethephon has shown to delay bud break up to 10 days in New Jersey and a 16-day delay was observed in New Zealand when applied at 100 mg L^{-1} rate during the fall after bud formation (Durner & Gianfagna, 1991). Sloan and Matta (1996) reported 3-, 7-, and 11-day delay on bud break in 'Redhaven' after application of 100, 200, and 400 mg L^{-1}, respectively. On three different peach cultivars, 'Correll', 'Redhaven', and 'Cresthaven', application of 50 to 500 mg L^{-1} ethephon induced a delay of 1 to 5 days, respectively, with 400 and 500 mg L^{-1} showing a cultivar-dependent reduction in fruit yield. In apricot, a 3- to 7-day delay was observed over two years when ethephon was applied at 100 mg L^{-1}, and at 300 mg L^{-1} it delayed bud break 8 to 10 days but resulted in flower abnormalities (Moghadam & Mokhtarian, 2006).

The extensive research in stone fruit suggests a potential for bud break delay in winegrapes, although there are differences between grape and stone fruit bud composition. Stone fruit dormant buds are flower buds that require low temperature exposure during winter (chilling period) to break dormancy. During this period, the floral bud continues to differentiate with warm temperatures and light exposure (Ram & Rao, 1984). Grapevine dormant buds are compound (latent) buds that contain a primary, secondary and tertiary bud (Srinivasan & Mullins, 1981; Williams, 2000; Vasconcelos et al., 2009). If the primary bud fails to grow or is damaged, the secondary bud emerges to resume growth of the vine. Tertiary buds can emerge if both primary and secondary buds

are killed or damaged. Grapevine compound buds are differentiated before dormancy and do not require a chilling period to break dormancy, although they do require exposure to warm temperatures and light (Morrison, 1991; Williams L.E., 2000). Stone fruit flower abnormalities and yield reduction from higher rates of ethephon application, as found in previous research, could be of concern for wine grapes. However, grape bud composition differences, such as cluster primordia differentiation before dormancy, could also play a significant role on crop damages from treatments of ethephon.

Research on ethephon applications to promote leaf abscission in grapevines to aid mechanical harvest and to facilitate pruning has shown to delay bud break the following spring (Anderson & Seeley, 1993). Additionally, ethephon treatments on grape cuttings of 'Chaush' at a rate of 800 mg L^{-1} have reportedly delayed bud break up to 19 days (Eris & Celik, 1981; Mannini & Ryugo, 1982; Anderson & Seeley, 1993).

2.1.5. Objective

The objective of this project was to evaluate the impact on rate and timing of applications of the plant growth regulator ethephon on timing of bud break. Delaying bud break by even a few days could be beneficial by avoiding exposure to late spring freeze.

2.2. Materials and methods

2.2.1. Locations

This research study was performed for two years in three separate locations, chosen because they are research vineyards (non-commercial), as ethephon is not labeled

for use on winegrapes to delay bud break. Also to avoid the use for two consecutive fall seasons, because carryover effects the second year are unknown.

Hill Country Study: The site was located near Fredericksburg, TX at the Texas A&M AgriLife Extension - Viticulture and Fruit Lab (lat. 30.247921, long. -98.909909). The soil series found at this location was a Tobosa clay, moist, 0 to 1 percent slopes and Luckenbach clay loam with 0-3 percent slopes (USDA-NRCS, 2017).

North Texas Study: The site was located at the T.V. Munson Memorial Vineyard in Denison TX (lat. 33.7087904, long. -96.6591438). The soil series at this site was a Normangee clay loam with 4 to 8 percent slopes (Soil Survey Staff, 2017).

Gulf Coast Study: The site was located in College Station, TX at the Texas A&M University 2818 Horticultural farm (lat. 30.623778, long. -96.3735669). The soil series at this location was Robco loamy fine sand, 1 to 5 percent slopes (Soil Survey Staff, 2017).

2.2.2. Plant material

In total, the following cultivars were used: Aglianico, Albarino, Albillo Mayor, Malbec, Rousanne, Sangiovese, Syrah, Tannat, Tempranillo, Vermentino, Viognier and Herbemont (Table 1). All cultivars were *Vitis vinifera* except for Herbemont, an interspecific hybrid (Vitis spp.). Sangiovese and Herbemont were grafted on 1103P rootstock only, whereas the other cultivars were grafted on 5BB and 1103P rootstocks. At all sites, the grapevine training system was cordon-spur with Vertical Shoot Position (VSP).

Table 1 Plant material utilized in the study, cultivar origin, berry color, location and year of application

Scion Cultivar	Origin	Berry color	Location	Year**
Aglianico	Italy	Black	Denison	2017
Albarino	Portugal/ Spain	White	Denison	2017
Albillo Mayor	Spain	White	Denison	2017
Herbemont*	United States	Black	College Station	2017
Malbec	France	Black	Denison	2017
Rousanne	France	White	Denison	2017
Sangiovese	Italy	Black	Fredericksburg	2015/2016
Syrah	France	Black	Denison	2017
Tannat	France	Black	Denison	2017
Tempranillo	Spain	Black	Denison	2017
Vermentino	Italy	White	Denison	2017
Viognier	France	White	Denison	2017

All cultivars were grafted onto 1103P and 5BB rootstock.
**Vitis* spp, all other scion cultivars are *V. vinifera*
**Year study was conducted.

2.2.3. Treatments

Hill Country Study: Treatments consisted of applying an ethephon product as a spray directed at canes at a rate of 145 mg L^{-1} ethephon per hectare (low rate, L) or 291 mg L^{-1} per hectare (high rate, H) at three different application timings: November (N), December (D) and January (J), and an untreated control (C) (Table 2).

Table 2 List of all treatments, rates, and timings for the hill country site

Treatment	Product amount	Rate	Timing	Abbreviation
Ethephon*	438.5 ml/ha	145 mg L^{-1}	November, 2015	LN
Ethephon	438.5 ml/ha	145 mg L^{-1}	December, 2015	LD
Ethephon	438.5 ml/ha	145 mg L^{-1}	January, 2016	LJ
Ethephon	877 ml/ha	291 mg L^{-1}	November, 2015	HN
Ethephon	877 ml/ha	291 mg L^{-1}	December, 2015	HD
Ethephon	877 ml/ha	291 mg L^{-1}	January, 2016	HJ
Control	-	-	-	C

Abbreviations: LN- Low rate November, LD- Low rate December, LJ- Low rate January, HN- High rate November, HD- High rate December, HJ- High rate January.
*Product contained 21.7% ethephon active ingredient.

Due to minimal plant material available of each cultivar represented, the following two sites only contained of a high rate and control.

North Texas Study: Treatments consisted of applying an ethephon product as a spray directed at canes at a rate of 291 mg L^{-1} ethephon per hectare in January (J) and March (M), and an untreated control (C) (Table 3).

Gulf Coast Study: This site treatment also consisted of applying an ethephon product as a spray directed at dormant canes at a rate of 291 mg L^{-1} ethephon per hectare in February (F) and an untreated control (C) (Table 3).

All treatments were applied using a 4-gallon (15.142 L) 475-B-DELUXE Backpack Sprayer (Solo, CITY, ST) with fan spray nozzle at 413.685 Kilopascal and an

average pace of 0.19 m/s. At all sites the grapevine training system was bilateral cordon with vertical shoot positioning (VSP).

Table 3 List of all treatments, rate, and timings for the north Texas and gulf coast study

Treatment	Product amount	Rate	Timing	Abbreviation
Ethephon*	343.6 mL ha^{-1}	291 mg L^{-1}	January, 2017	HJ
Ethephon	343.6 mL ha^{-1}	291 mg L^{-1}	February, 2017	HF
Ethephon	343.6 mL ha^{-1}	291 mg L^{-1}	March, 2017	HM
Control	-	-	-	C

Abbreviation: HJ- High rate January, HF- High rate February, HM- High rate March
*Product contained 55.4% ethephon active ingredient.

2.2.4. Experimental design

Hill Country Study: The research plot consisted of four rows of 25 vines each, and each experimental unit consisted of three vines with a buffer vine between each treatment and border vine on each row end (Figure 1). The experimental design was completely randomized with three replications per treatment.

North Texas Study: This plot was designed with one panel of two consecutive vines per cultivar per row for a different project. There were 120 total panels available on a total of six rows. Each row was designed as an experimental block, thus each row had 20 panels representing 10 cultivars and 2 rootstocks described previously in plant

material. Treatments were completely randomized by row blocks, on alternating rows of ethephon treatment and control (Figure 2).

Gulf Coast Study: This site consisted of two rows with space for 24 vines total, of which 20 were used for the plot design. This plot design was completely randomized between the two rows for the one treatment and control. Thus treatment and control consisted of ten individual vine replications (Figure 3).

Panel #*		1		2		3		4		5		6	
Row 21	X	X	X	C	X	HN	X	HD	X	LN	X	HN	X
Row 22	X	HJ	X	HD	X	C	X	HJ	X	HD	X	LJ	X
Row 23	X	HJ	X	LJ	X	HN	X	X	X	LD	X	C	X
Row 24	X	LN	X	LJ	X	LD	X	LD	X	LN	X	X	X

Figure 1 Experimental design at hill country site
*Panel # per row, consists of 3 vine repetitions each.
Abbreviations: C- Control, HN- High rate November, LN- Low rate November, HD- High rate December, LD- Low rate December, HJ- High rate January, LJ- Low rate January and X- missing or buffer vines.
The cultivar Sangiovese on 1103P rootstock was used at this site.

Panel #		Row 24	Row 25	Row 26	Row 27	Row 28	Row 29	
		H	U	H	U	H	U	
1	X	X	X	X	X	X	X	X
2	X	Al/ 5BB	X	Vi/ 1103P	Ag/ 1103P	Te/ 5BB	Ta/ 1103P	X
3	X	Te/ 5BB	Al/ 1103P	X	R/ 1103P	Ve/ 1103P	Ag/ 1103P	X
4	X	S/ 5BB	Ve/ 5BB	M/ 1103P	AM/ 1103P	R/ 1103P	Vi/ 1103P	X
5	X	R/ 5BB	X	Vi/ 5BB	Al/ 5BB	AM /1103P	X	X
6	X	X	AM/ 1103P	S/ 5BB	M/ 1103P	X	Vi/ 5BB	X
7	X	Ag/ 1103P	Vi/ 5BB	Al/ 1103P	X	M/ 1103P	X	X
8	X	Ag/ 5BB	AM/ 5BB	Ve/ 1103P	Te/ 1103P	Ve/ 5BB	Te/ 5BB	X
9	X	Ta/ 1103P	Vi/ 1103P	X	S/ 5BB	Te/ 1103P	X	X
10	X	Vi/ 5BB	S/ 5BB	R/ 1103P	S/ 1103P	Al/ 5BB	M/ 1103P	X
11	X	AM/ 1103P	M/ 5BB	S/ 1103P	Ta/ 1103P	X	S/ 1103P	X
12	X	Vi/ 1103P	Ag/110 3P	Te/ 5BB	Ag/ 5BB	X	X	X
13	X	Te 1103P	Ag/5B B	R/ 5BB	M/ 5BB	Ta/ 5BB	AM/ 1103P	X
14	X	M/ 5BB	Al/5BB	Ag/ 5BB	X	R/ 5BB	M/5BB	X
15	X	R/ 1103P	Te/110 3P	X	X	X	AM/ 5BB	X
16	X	Ve/ 5BB	X	AM/ 1103P	X	Ag/ 5BB	R/ 1103P	X

Figure 2 Experimental design at north Texas site
Panel # consists of 2 vine repetions each.
Colors: Blue- January treatment, Green- March Treatment, Yellow- Control (untreated vines)
Abbreviations: Ag- Aglianico, Al- Albarino, AM- Albillo Mayor, M- Malbec, R- Rousanne, S- Syrah, Ta- Tannat, Te- Tempranillo, Ve- Vermentino, Vi– Viognier, 5BB- Kober 5BB, 1103P- Paulsen 1103, X- mising or border vines, H- High rate treatment row, U- Untreated row

Panel #		Row 24	Row 25	Row 26	Row 27	Row 28	Row 29	
		H	U	H	U	H	U	
17	X	M/ 1103P	Te/ 5BB	Ve/ 5BB	Vi/ 1103P	X	Al/ 5BB	X
18	X	Al/ 1103P	S/ 1103P	Ta/ 1103P	AM/ 5BB	S/ 5BB	Te/ 1103P	X
19	X	X	M/ 1103P	AM/ 5BB	Vi/ 5BB	Vi/ 1103P	R/ 5BB	X
20	X	AM/ 5BB	R/ 1103P	Te/ 1103P	Te/ 5BB	Vi/ 5BB	S/ 5BB	X
21	X	S/ 1103P	Ta/ 1103P	Ag/ 1103P	Ve/ 5BB	M/ 5BB	X	X
22	X	X	X	X	X	X	X	X

Figure 2 continued

Vine #	1	2	3	4	5	6	7	8	9	10	11	12
Row 1	C	X	C	HF	HF	HF	X	C	C	C	HF	C
Row 2	HF	HF	X	C	C	HF	HF	X	HF	C	C	HF

Figure 3 Experimental design at gulf coast site
Abbreviations: C- Control, HF- High rate February and X- missing vines
The cultivar Herbemont on 1103P rootstock was used at this site.

2.2.5. Data collection

The bud burst stage of grapevines according to the Eichhorn and Lorenz scale is at green tip, when first leaf tissue is visible and development stage of shoots is after bud break when rosette of leaf tips is visible (Keller, 2015). For this project, bud break and shoot development was determined according to this description.

For the Hill Country Study, data collection consisted of rating the percentage of overall bud break every 2-3 days from the start of bud break until full bud break was achieved during the spring. Rating was on a 0-5 scale, where 0: 0%, 1: 1-20%, 2: 21-40%, 3: 41-60%, 4: 61-80% and 5: 81-100%.

For the North Texas Study, data collection consisted of individual bud break counts and average of shoot length per cane per vine. Canes at this site had considerably less buds per cane that those at the Gulf Coast Study, therefore all bud breaks were count per cane. Data also collected on shoot diameter midway between first and second nodes at the base of each cane per vine at the end of the season using a digital caliper (Carbon Fiber Composites, Shanghai, China) to assess secondary effects of treatments on vegetative growth.

Data collection for the Gulf Coast Study consisted of individual bud break counts and average shoot length of first five buds located at cane base and last five buds located at cane tip per cane per vine. Bud break counts and average shoot length measurements were collected once at 50% bud break of control. Cluster counts and shoot diameter, midway between first and second nodes at the base of each cane per vine at the end of the season, were also determined to assess secondary effects of treatments on cluster count and vegetative growth.

2.2.6. Statistical analysis

Statistical analyses were conducted with JMP® statistical software from SAS (SAS Institute, Cary, NC). Data were subjected to the Proc GLM procedure and means were separated using the Fischer's protected least significant difference (LSD) at the

5% significance level. Ordinal data such as bud break rating was analyzed using a non-parametric approach, the Wilcoxon Rank Sum test. Regression analysis was conducted on continuous data, for instance bud break count. Factorial ANOVA was used to analyze bud break delay differences between rate and timing of application per individual site.

2.3. Results and discussion

There was an ethephon by location interaction for bud break percentage, fruit count, and shoot diameter comparisons. For this reason, the ethephon treatments are discussed by location.

2.3.1. Hill country study

Results of the six treatments and control showed few differences on bud break rating for the first date of data collection (Figure 4). The significance found was on HJ compared to LN and C (Table 4). Both the LN and C were advanced on bud break whereas HJ was behind the other treatments (Figure 4).

The second set of data was collected on March 18, 2016 (Figure 5). These results showed a greater number of significant differences between LN to those applied in HN, HD, HJ, LD, LJ, and C (Table 4). Overall, the LN treatment showed the most advancement of bud break when compared to all other treatments, including the control. These effects could have been due to the low rate and application timing on November when leaves where still present on the canopy. The application could have acted as a defoliant only, and not for dormancy delay. However, the results are in contrast to

observations of post-harvest/fall ethephon treatments for defoliation that resulted in bud break delay the following spring (Mannini et al., 1983: Szyjewicz et al., 1984: Anderson & Seeley, 1993: Lavee & May, 1997), although during these observations included higher concentrations of ethephon (500, 2000, and 5000 mg L^{-1}), and at a different timing (October), thus possibly a different physiological state. HJ showed most significance when compared with control, as it was the furthest behind in bud break (Figure 5).

The next set of data collection was on March 20, 2016 (Figure 6). Results from this date were similar to those from March 18. There was great significance when comparing LN to HN, HD, HJ, LD and LJ, as well as LD to C (Table 4). Although LN compared to C at this point shows less significance from March 18, C starts to catch up with bud break of LN (Figure 6).

The last set of data was collected on March 22, 2016. Significant differences were also observed when comparing LN to HN, HD, HJ, LD and LJ (Table 4). The Control and LN remained the furthest advanced on bud break (Figure 7).

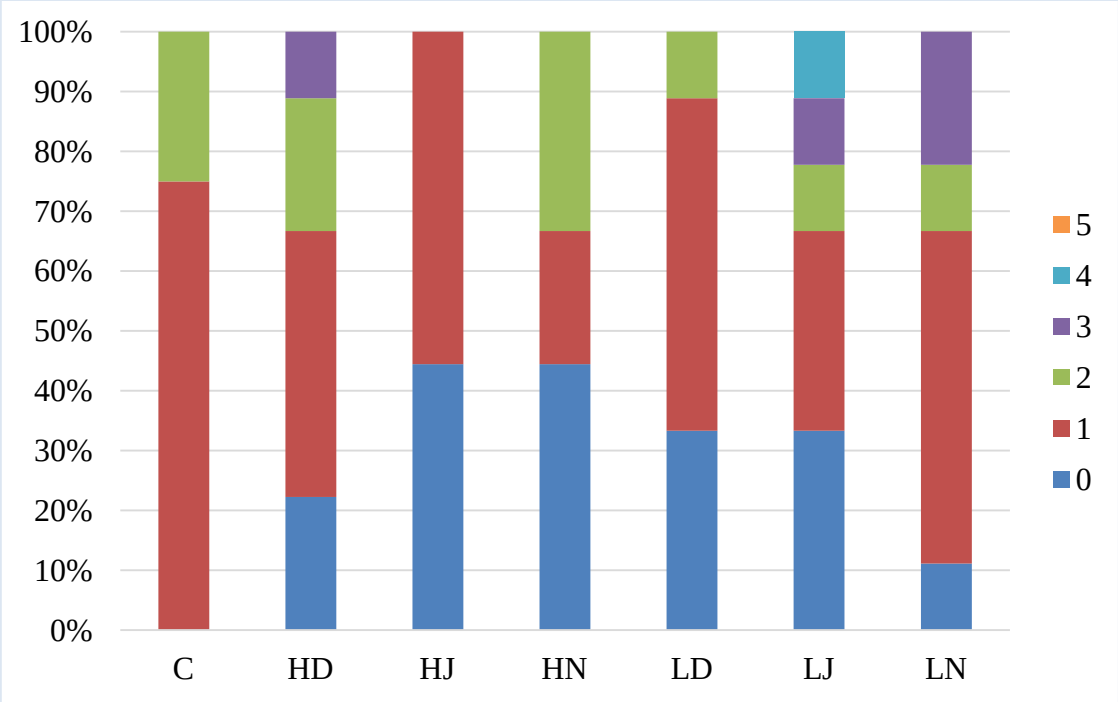

Figure 4 Hill country study ethephon effects on bud break rating, data collected on March 15, 2016
Abbreviations: C- Control, HD- High rate December, HJ- High rate January, HN- High rate November, LD- Low rate December, LJ- Low rate January, LN- Low rate November. 0: 0%, 1: 1-20%, 2: 21-40%, 3: 41-60%, 4: 61-80%, 5: 81-100%
The cultivar Sangiovese on 1103P rootstock was used.

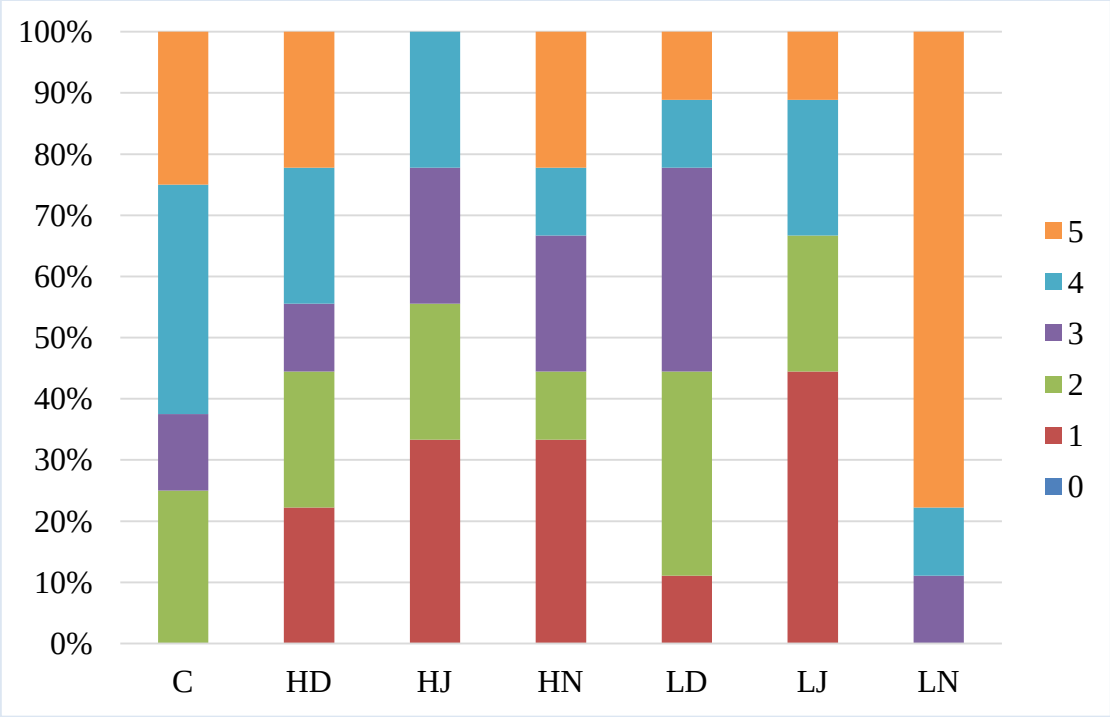

Figure 5 Hill country study ethephon effects on bud break rating data collected on March 18, 2016
Abbreviations: C- Control, HD- High rate December, HJ- High rate January, HN- High rate November, LD- Low rate December, LJ- Low rate January, LN- Low rate November. 0: 0%, 1: 1-20%, 2: 21-40%, 3: 41-60%, 4: 61-80%, 5: 81-100%
The cultivar Sangiovese on 1103P rootstock was used.

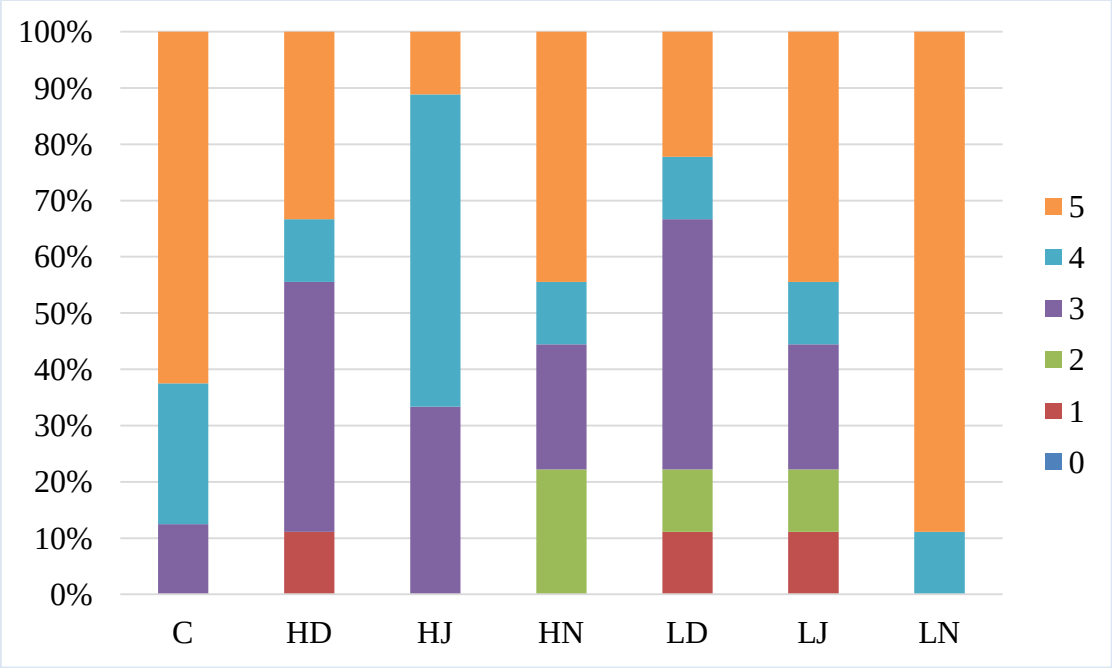

Figure 6 Hill country study ethephon effects on bud break rating data collected on March 20, 2016
Abbreviations: C- Control, HD- High rate December, HJ- High rate January, HN- High rate November, LD- Low rate December, LJ- Low rate January, LN- Low rate November. 0: 0%, 1: 1-20%, 2: 21-40%, 3: 41-60%, 4: 61-80%, 5: 81-100%
The cultivar Sangiovese on 1103P rootstock was used.

Figure 7 Hill country study ethephon effects on bud break rating data collected on March 22, 2016
Abbreviations: C- Control, HD- High rate December, HJ- High rate January, HN- High rate November, LD- Low rate December, LJ- Low rate January, LN- Low rate November. 0: 0%, 1: 1-20%, 2: 21-40%, 3: 41-60%, 4: 61-80%, 5: 81-100%
The cultivar Sangiovese on 1103P rootstock was used.

Table 4 Hill country study data analysis for bud break rating by treatment (p-values by date)

Treatment[y]	- Treatment	3-15-16	3-18-16	3-20-16	3-22-16
LN	HJ	0.044*[z]	0.001*	0.0017*	0.0047*
LN	LD	0.1567	0.0033*	0.004*	0.0047*
LJ	HJ	0.2723	0.9267*	0.8903	0.8869
LN	HN	0.2872	0.012*	0.0398*	0.0332*
HN	HJ	0.5029	0.6172	0.8903	0.8869
LD	HJ	0.5136	0.4955	0.285	1
LJ	LD	0.5398	0.3893	0.491	0.8869
LJ	HN	0.6109	0.5825	0.9628	1
LN	LJ	0.675	0.0033*	0.04*	0.0332*
LN	HD	0.7039	0.0157*	0.0132*	0.0335*
LN	C	0.8653	0.0404*	0.2173	0.1442
LJ	HD	0.9632	0.3622	0.8526	0.8826
LD	HN	0.8873	0.9639	0.4346	0.8869
HD	C	0.8705	0.4293	0.1212	0.4612
LJ	C	0.7138	0.0834	0.2712	0.394
HN	HD	0.5163	0.7865	0.8164	0.8826
HN	C	0.3779	0.2802	0.2708	0.394
LD	HD	0.3386	0.8214	0.5745	0.6667
LD	C	0.1259	0.1817	0.0378*	0.1811

[y] Abbreviations: C- Control, HD- High rate December, HJ- High rate January, HN- High rate November, LD- Low rate December, LJ- Low rate January, LN- Low rate November
[z] Wilcoxon nonparametric multiple comparison test; values followed by * indicate a difference at the 0.05 probability level.

Table 4 continued

Treatment[y]	- Treatment	3-15-16	3-18-16	3-20-16	3-22-16
HJ	HD	0.123	0.3659	0.7796	0.6667
HJ	C	0.0198*	0.0545	0.0572	0.1811

The overall results showed at most a 2-day bud break delay with the high rate January treatment, followed by low rate in December, and almost all other applications for the Hill Country study were delayed one day when compared to the control. These results are consistent with a delay in bud break noted in previous research by Eris & Celik (1981), Mannini & Ryugo (1982), Mannini et al. (1983), Szyjewicz et al. (1984), Anderson & Seeley (1993) and Lavee & May (1997). However, the difference in bud break between the control and ethephon treatments observed in this experiment were much less in comparison to the 19-day bud break delay observed in cuttings of 'Chaush' by Eris & Celik (1981). Furthermore, the low rate application in November had adverse effects of advancing bud break between 2 and 3 days which has not been observed in previous research. There was no visible toxicity damage on the application rate, therefore there was no data collected on vine damage.

2.3.2. North Texas study

There was great significance on percent bud break between treatments and cultivar for the month of January application, whereas the March application only showed strong significance by cultivar and not by treatment (Table 5). The least square

mean difference on bud break was 8.07% between treatment and control for January and 0.08% difference for March. The Student's t test also confirmed the results of the differences (Table 6). These results demonstrate that the January application had a greater treatment effect on bud break delay than the March application. Differences in bud break amongst cultivars were expected as this is commonly observed. The findings of cultivar dependence are similar to those observed by Mannini & Ryugo (1982) and Mannini et al. (1983), who noted that three grapevine cultivars had a different bud break timing in the following order, Barbera, Flame Tokay and Carignane. Rootstock did not impact bud break timing, except on the scion cultivar Syrah (Table 7).

Shoot diameter measurements ranged from 6.47 to 8.13 mm across cultivars and rootstocks and although there were significant differences in cane shoot diameter by cultivar, no differences were observed by treatment (Table 5). Only Abillo Mayor (AM) on different rootstock displayed differences in shoot diameter measurements based on Student's t test (Table 8).

The overall results from this site suggest that ethephon application in January is more effective at delaying bud break than applications in March, although the effect was highly dependent on cultivar. Shoot diameter was not affected by the application of ethephon.

Table 5 North Texas study, p-values for % bud break and shoot diameter measurements of treatments on January and March

Measurement type and month	Treatment	Cultivar	ANOVA
Bud Break January	0.0013*	<0.0001*	<0.0001*
Bud Break March	0.9737	<0.0001*	<0.0001*
Shoot diameter** January	0.5283	<0.0001*	<0.0001*
Shoot diameter March	0.3018	<0.0001*	0.0001*

Values followed by * indicate a difference at the 0.05 probability level.
** Shoot diameter was measured in millimeters.

Table 6 North Texas study data analysis of % bud break and shoot diameter measurement by treatment and month

Data analysis type	Treatment	Std Error	Mean	Student's t test
% Bud Break	CJ	1.86	52.56	A
% Bud Break	HJ	1.68	46.03	B
% Bud Break	CM	2.10	51.46	A
% Bud Break	HM	2.12	51.63	A
Shoot Diameter*	CJ	0.12	7.52	A
Shoot Diameter	HJ	0.10	7.46	A
Shoot Diameter	CM	0.14	7.56	A
Shoot Diameter	HM	0.13	7.44	A

*Shoot diameter was measured in millimeters
Abbreviations: CJ- Control January, HJ- High rate January, CM- Control March, HM- High rate March.

Table 7 North Texas study, % bud break data analysis by cultivar and month

Month	Treatments	Std Error	Mean	Tukey HSD
January	Vi/1103P	4.03	64.24	A
January	R/5BB	4.27	54.94	AB
January	S/5BB	3.68	52.19	AB
January	Al/1103P	5.55	50.75	ABC
January	R/1103P	3.35	51.46	ABC
January	Al/5BB	4.12	51.28	ABC
January	Te/5BB	3.32	45.29	BC
January	Ag/5BB	3.45	44.13	BC
January	M/1103P	2.95	44.63	BC
January	S/1103P	4.57	34.65	C
March	Ta/1103P	2.14	63.90	A
March	Ta/5BB	9.21	59.69	ABC
March	Vi/5BB	3.68	58.21	ABC
March	Ag/1103P	3.57	56.70	ABC
March	Ve/5BB	4.57	51.10	ABC
March	AM/1103P	3.62	42.97	BC
March	Ve/1103P	9.94	41.43	ABC

Abbreviations: Ag- Aglianico, Al- Albarino, AM- Albillo Mayor, M- Malbec, R- Rousanne, S- Syrah, Ta- Tannat, Te- Tempranillo, Ve- Vermentino, Vi- Viognier, 1103P- Paulsen 1103, 5BB- Kober 5BB

Table 7 continued

Month	Treatments	Std Error	Mean	Tukey HSD
March	M/5BB	4.41	41.08	BC
March	Te/1103P	3.61	38.22	C
March	AM/5BB	3.44	34.44	C

Table 8 North Texas study, shoot diameter measurement data analysis by cultivar and month

Month	Treatments	Std Error	Mean	Tukey HSD
January	Te/5BB	0.21	8.40	A
January	S/5BB	0.22	8.29	A
January	S/1103P	0.24	8.07	AB
January	Ag/5BB	0.22	7.91	AB
January	M/1103P	0.21	7.10	BC
January	R/5BB	0.25	7.05	BC
January	R/1103P	0.21	7.08	BC
January	Al/5BB	0.28	6.95	BC
January	Vi/1103P	0.20	6.81	C
January	Al/1103P	0.47	6.47	BC

Abbreviations: Ag- Aglianico, Al- Albarino, AM- Albillo Mayor, M- Malbec, R- Rousanne, S- Syrah, Ta- Tannat, Te- Tempranillo, Ve- Vermentino, Vi- Viognier, 1103P- Paulsen 1103, 5BB- Kober 5BB

Table 8 continued

Month	Treatments	Std Error	Mean	Tukey HSD
March	AM/5BB	0.22	8.13	A
March	Ta/5BB	0.57	7.91	ABC
March	M/5BB	0.28	7.96	AB
March	Ta/1103P	0.21	7.87	AB
March	Ve/1103P	0.50	7.76	ABC
March	Ve/5BB	0.30	7.67	ABC
March	Te/1103P	0.31	7.59	ABC
March	Ag/1103P	0.28	7.18	ABC
March	AM/1103P	0.24	7.11	BC
March	Vi/5BB	0.20	6.69	C

2.3.3. Gulf coast study

The Student's t test showed significant results by treatment on bud break of the first 5 buds, located at the cane base. A mean of 2.26 broken buds out of 5 for High rate treatment applied in February compared to a mean of 2.57 broken buds for control, thus bud break for treatment was further behind compare to control. However, there was no significant difference in bud break of last 5 buds located at the cane tip when compared to first 5 buds located at the cane base, or the average shoot height of either first or last 5

buds (Table 9). ANOVA and Wilcoxon test confirmed results of the Student's t test on bud break and average shoot length (Table 11).

Shoot diameter measurements revealed no significant differences between treatments from Student's t test (Table 10), ANOVA or Wilxocon test (Table 11). Shoot diameter measurements were approximately 6.5 mm for both treatments, with 0.03 mm difference in least square means of HF and C (Table 10).

However, significant differences in cluster numbers per vine were observed. The ethephon treated vines had approximately 7 clusters per vine more than the untreated control, or approximately 18% more clusters. These results were significant for the student's t test, ANOVA and Wilcoxon test, all with p-values of <0.0001 (Table 10 & 11).

The overall results can be summarized as ethephon applied in February did not result in a significant delay in bud break or affect vine vigor as determined by shoot diameter. However, this treatment resulted in a higher cluster quantity (potential yield), in contrast to the results of a yield decrease by ethephon treatments reported in peach (Crisosto et al., 1990; Sloan and Matta, 1996).

Table 9 Gulf coast study, bud break and shoot height measurements by treatment

Measurement Type	Treatments	Std Error	Mean	Student's t Test
Bud Break of 1st 5 buds	C	0.09	2.57	A
Bud Break of 1st 5 buds	HF	0.09	2.26	B
Avg shoot ht of 1st 5 buds	C	0.19	3.72	A
Avg shoot ht of 1st 5 buds	HF	0.18	3.38	A
Bud Break of last 5 buds	C	0.09	2.67	A
Bud Break of last 5 buds	HF	0.09	2.74	A
Avg shoot ht of last 5 buds	C	0.19	3.80	A
Avg shoot ht of last 5 buds	HF	0.18	3.69	A

Abbreviations: C- Control, HF- High rate February

Table 10 Gulf coast study, shoot diameter measurements in millimeters and cluster count by treatment

Measurement Type	Level	Std Error	Mean	Student's t Test
Shoot Diameter	C	0.09	6.51	A
Shoot Diameter	HF	0.09	6.48	A
Cluster Count	C	1.03	30.78	A
Cluster Count	HF	0.98	37.66	B

Abbreviations: C- Control, HF- High rate February

Table 11 Gulf coast study, p-values for bud break, average shoot height, shoot diameter measurements and cluster count

	p-values		
Measurement Type	ANOVA	Effects test	Wilcoxon
Bud Break of 1st 5 buds	0.0167*	0.0167*	0.0262*
Avg. shoot ht of 1st 5 buds	0.1860	0.1860	0.0696
Bud Break of last 5 buds	0.6010	0.6010	0.5399
Avg. shoot ht of last 5 buds	0.6840	0.6840	0.9275
Shoot diameter	0.8313	0.8313	0.7604
Cluster	<0.0001*	<0.0001*	<0.0001*

Values followed by * indicate a difference at the 0.05 probability level.

CHAPTER III

EVALUATING THE IMPACT OF DELAYED PRUNING ON CLUSTER COUNT IN WINEGRAPES

3.1. Introduction and literature review

3.1.1. Dormant buds

Grapevine dormant (latent) buds are compound buds that contain a primary, a secondary and a tertiary bud (Srinivasan & Mullins, 1981; Williams L.E., 2000; Vasconcelos et al. 2009). The primary bud is the most developed bud containing leaf and cluster primordia that are differentiated before dormancy, resulting in a higher yield potential than secondary and tertiary buds. Secondary buds contain leaf primordia and may produce cluster primordia depending on the cultivar, but fruitfulness is generally lower than primary buds. Tertiary buds typically produce leaf primordia only and thus no fruit (Srinivasan & Mullins, 1981; Morrison, 1991; Friend et al., 2011). During dormant pruning, growers leave specific numbers of dormant buds on vines as a means of regulating crop yield and directing shoot growth.

3.1.2. Delayed pruning

Delayed pruning, or pruning at or after bud beak, has been recommended in place of mid-winter pruning as a means to delay bud break on cordon-spur pruned vines to avoid late spring freeze/frost damage. Martin and Dunn (2000) reported an average delay in bud break of 4 days by using delayed pruning with no significant adverse effects on

the number of flowers per inflorescence. However, the authors observed that high temperatures near bud break resulted in fewer flowers per inflorescence which could be a concern as delayed pruning increases the potential of exposure to higher temperatures at bud break later in the spring (Dunn & Martin, 2000). Other research conducted on delayed pruning, soon after bud break, reported an increase in yield of 63-93%, shorter shoot length, and no impact on cluster composition when compared to mid-winter pruning. The higher yield was reported to result from an increase in average bunch weight by having more seeded than seedless berries or green ovary berries per bunch, although the underlying physiology was not determined (Friend & Trought, 2007).

3.1.3. Late delayed pruning

Bud break in grapevines is influenced by apical dominance and corollary inhibition, thus, bud break occurs at the cane apex first on non-pruned canes before commencing further down the cane. The shoots that develop at the can apex are most prone to frost exposure because of their earlier emergence. After a late spring frost event occurs or after the risk of frost has past, delayed pruned vines are then final-pruned to the desired number of buds which includes the lowest 1 to 4 buds on canes of spur-pruned vines. Research results suggest that the delay in bud break of the buds retained at final pruning in delayed pruning is a reliable method to prevent late spring frost damage (Dunn & Martin 2000, Friend and Trout 2007). However, research on the impact of delayed pruning on grapevine fruitfulness is limited.

3.1.4. Objective

The objective of this study is to compare the effects of delay pruning at 50% bud break and 3 weeks after on the fruitfulness of the shoots retained after final pruning.

3.2. Materials and methods

3.2.1. Plant material

This study used eight different cultivars/selections: Blanc du Bois, Norton, Victoria Red, U0502-10, U0502-20, U0502-26, U0502-38, and U0505-35 on 5BB rootstock (Table 12).

3.2.2. Location

The research site was located at Industry, TX, in the Texas Gulf Coast Region where a grape cultivar trial was established in 2012. Vines were spur pruned and shoots were vertically positioned (VSP). The soil series was a Renish clay loam, 5 to 20 percent slopes and Cuero loam, 5 to 8 percent slopes (Soil Survey Staff, 2017). Vine management was performed according to standard practices for hybrid winegrapes in the Texas Gulf Coast.

3.2.3. Treatments

Treatments consisted of pruning at 50% bud break (Early Pruning), when 50% of the buds on a vine had reached the green tip stage defined by Eichorn and Lorenz (Keller, 2015) and pruning 3 weeks after 50% bud break (Late Pruning).

Table 12 Plant material for delayed pruning study

Genotype*	Parentage	Berry Color
Blanc du Bois	Fla D6-148 x Cardinal	White
Norton	*V. spp*	Black
U0502-10	A81-138 x Chardonnay**	Black
U0502-20	A81-138 x Chardonnay**	White
U0502-26	A81-138 x Chardonnay**	Black
U0502-38	A81-138 x Chardonnay**	Black
U0505-35	A81-138 x Cab. Sauvignon**	Black
Victoria Red	Arkansas 1123*** x Exotic	Bright Red

* All genotypes are of American origin, all on 5BB rootstock located at Industry, TX site.
** 88% *V. Vinifera*
*** Includes Villard blanc, Jacquez, Herbemont, Vitis berlandieri

3.2.4. Experimental design

The research plot consisted of nine rows, each containing three consecutive vines of each cultivar/selection in a completely randomized design. The research plot was divided in two parts for this study, first five rows were used for early pruning and last four rows were used for late pruning treatment (Figure 8).

Vine #	Cultivar/selection								
	Row 1	Row 2	Row 3	Row 4	Row 5	Row 6	Row 7	Row 8	Row 9
	EP	EP	EP	EP	EP	LP	LP	LP	LP
1	26	BdB		35	38	Nor	Vic	10	20
2	26	BdB		35	38	Nor	Vic	10	20
3	26	BdB		35	38	Nor	Vic	10	20
4	Nor	26	35	Vic	20	38	10		BdB
5	Nor	26	35	Vic	20	38	10		BdB
6	Nor	26	35	Vic	20	38	10		BdB
7	35	Nor	38	10	26	Vic	20	BdB	
8	35	Nor	38	10	26	Vic	20	BdB	
9	35	Nor	38	10	26	Vic	20	BdB	
10		Vic	10	35	20	BdB	Nor	26	38
11		Vic	10	35	20	BdB	Nor	26	38
12		Vic	10	35	20	BdB	Nor	26	38
13	Vic	BdB	20	10		35	26	38	Nor
14	Vic	BdB	20	10		35	26	38	Nor
15	Vic	BdB	20	10		35	26	38	Nor
16	38	26	35	Nor	Vic	20	10	BdB	
17	38	26	35	Nor	Vic	20	10	BdB	
18	38	26	35	Nor	Vic	20	10	BdB	
19	10	Nor		BdB	35	26	20	Vic	38
20	10	Nor		BdB	35	26	20	Vic	38
21	10	Nor		BdB	35	26	20	Vic	38
22	BdB	20	Vic		26	35	38	Nor	10
23	BdB	20	Vic		26	35	38	Nor	10
24	Bla	20	Vic		26	35	38	Nor	10

Figure 8 Industry TX, delayed pruning study experimental design
Abbreviations: EP- Early Pruning, LP- Late Pruning, BdB- Blanc du Bois, Nor- Norton, Vic- Victoria Red, 10- U0502-10, 20- U0502-20, 26- U0502-26, 35- U0505-35, 38- U0502-38,
All cultivar/selections were grafted on 5BB rootstock.

3.2.5. Data collection

Data collection on vine fruitfulness consisted of counting the number of clusters per vine at harvest. Vine vigor was assessed at harvest by measuring shoot diameter midway between first and second nodes at the base of 10 randomly selected canes per vine using a digital caliper (Carbon Fiber Composites, Shanghai, China).

3.2.6. Statistical analysis

Statistical analyses were conducted with JMP® statistical software from SAS (SAS Institute, Cary, NC). Data was performed as factorial analysis of variance (ANOVA) and means were separated using the Fischer's protected least significant difference (LSD) at the 5% significance level.

ANOVA and regression analysis were conducted to analyze cluster count and shoot diameter measurements by timing of pruning and cultivar/selection.

3.3. Results and discussion

3.3.1. Industry, Texas site

The differences in cluster count were statistically significant with ANOVA p-value of <0.0001. Cluster count also shows great significance in effects test by shoot diameter (p-value = 0.0021), by cultivar (p-value <0.001), by treatment (p-value <0.001), and by treatment*cultivar interaction (p-value <0.001). Results of shoot diameter by cultivar has statistical significance with ANOVA p-value of <0.001 (Table 13). Student's t-test results on cluster count by treatment also shows great difference,

with LS mean value at early pruning of 16.45 and 9.15 at late pruning treatment (Table 14). Thus, cluster count was significantly reduced by late pruning. The early pruning timing in this study was equivalent to the later pruning timing reported by Friend & Trought (2007), where a higher number of clusters was reported. However the low cluster number for this research for late pruning may be due to higher temperatures during shoot development, similar to the report on flowering of delayed pruning that had fewer flowers per inflorescence as temperature increases on day of bud break (Dunn & Martin, 2000). Cluster counts varied by cultivar when analyzed using Tukey HSD multiple comparison test, although some cultivar pairs have no difference on cluster count when compared to one another, such as Vic to 35, 38 to 20, 20 to 26, and 26 to 10 (Table 15).

Table 13 Industry, TX statistical values for cluster count and shoot diameter

		p-values			
	ANOVA	Effects test Shoot Diameter	Effects test Cultivar	Effects test Treatment	Effects test Treatment * Cultivar
Cluster by shoot diameter, cultivar and treatment	<0.0001*	0.0021*	<0.001*	<0.001*	<0.001*
Shoot diameter by cultivar	<0.001*	0.0006*	<0.001*	N/S	N/S

Values followed by * indicate a difference at the 0.05 probability level.
N/S- Non Significant

Table 14 Industry, TX cluster count by treatment

Treatment	Std Error	Mean	Student's t test
EP	0.32	18.44	A
LP	0.25	8.60	B

Abbreviations: EP- Early Pruning, LP- Late Pruning

Table 15 Industry, TX cluster count by cultivar

Cultivar	Std Error	Mean	Tukey HSD
Nor	0.54	37.27	A
BdB	0.53	25.17	B
Vic	0.57	11.35	C
35	0.56	11.79	C
38	0.60	5.24	D
20	0.67	3.00	DE
26	0.57	3.05	E
10	0.54	2.14	E

Abbreviations: BdB- Blanc du Bois, Nor- Norton, Vic- Victoria Red, 10- U0502-10, 20- U0502-20, 26- U0502-26, 35- U0505-35, 38- U0502-38,

Tukey HSD test of cluster count compared by treatment and cultivar shows greater differences by cultivar for EP treatment than by cultivar for LP treatment (Table 16). LP treatment cluster count results are low cluster counts (<4.22 average clusters per vine) for Vic, 35, 38, 20, 26, and 10. Although, with exception of Nor (>32) and BdB (>22), which can be due to Nor late bud break and harvest period, whereas BdB is highly vigorous and heavy cropper. The results of BdB and Nor hybrids are similar to previous research that found hybrids are more prone to overcrop (more fruitful) when compare to *V. vinifera* cultivars (Pool et at., 1978; Dami et al., 2006). Further research has demonstrated that these hybrids have more secondary bud fruitfulness and fruitful basal buds, non-latent/compound buds (Pool et at., 1978; Morris et al., 2004). As a result of hybrids being more fruitful overall, this can explain the differences in cluster count from late pruning effects, where the 88% *vinifera* has an effect on selections 10, 20, 26, 35, and 38.

Shoot diameter measurement results show significant differences by ANOVA test with p-value of <0.001 and Tukey HSD test, however Tukey's test differences are close within some cultivars (Table 17). There are no significant differences among shoot diameter measurements by treatment (data not shown).

Table 16 Industry, TX cluster count by treatment and cultivar

Treatment by Cultivar	Mean	Std Error	Tukey HSD
EP,Nor	42.44	0.79	A
LP,Nor	32.88	0.73	B
EP,BdB	27.83	0.76	C
LP,BdB	22.36	0.73	D
EP,Vic	20.01	0.84	DE
EP,35	17.87	0.75	E
EP,38	9.10	1.03	F
EP,20	6.04	1.18	FG
EP,26	4.64	0.93	FGH
LP,35	4.22	0.84	GH
LP,38	3.99	0.61	GH
LP,Vic	3.95	0.76	GH
EP,10	3.67	0.80	GH
LP,26	2.37	0.65	GH
LP,20	2.33	0.64	GH
LP,10	1.11	0.73	H

Abbreviations: EP- Early Pruning, LP- Late Pruning, BdB- Blanc du Bois, Nor- Norton, Vic- Victoria Red, 10- U0502-10, 20- U0502-20, 26- U0502-26, 35- U0505-35, 38- U0502-38,

Table 17 Industry, TX shoot diameter measurement data analysis

Cultivar	Std Error	Mean	Tukey HSD
Vic	0.15	7.50	A
BdB	0.16	7.60	AB
35	0.15	6.88	ABC
26	0.16	6.59	BC
38	0.15	6.63	BC
10	0.16	6.43	BC
Nor	0.20	7.04	C
20	0.16	6.26	C

Abbreviations: BdB- Blanc du Bois, Nor- Norton, Vic- Victoria Red,
10- U0502-10, 20- U0502-20, 26- U0502-26, 35- U0505-35, 38- U0502-38,

CHAPTER IV

CONCLUSIONS

4.1. Conclusions for chapter II

Late spring freeze/frost damage is a significant weather related problem for grape production in the United States. There are multiple means of protection to avoid late frost/freeze damage, however many of this methods are impractical. This study evaluated the effects of ethephon spray to delay bud break in the spring at three different locations in Texas.

The ethephon treatments applied in November, December, February and March did not have as great of an impact on delaying bud break as January applications. In contrast, the low rate of ethephon applied in November actually advanced bud break which is undesirable. Although a rate response was observed in this study, the results from the North Texas site suggest that the impact of ethephon may be cultivar dependent which has been reported in stone fruit. In summary, the inconsistencies observed in this study indicate that more research on the use of ethephon to delay bud break is needed before it can be recommended as a method of frost protection.

4.2. Conclusions for chapter III

Late spring freeze/frost damage is a significant problem for grape production worldwide. Delayed pruning is a method practiced by growers to delay bud break and avoid spring frost damage. However, delaying pruning passed full bud break has not

been studied to a great extent. This study evaluated the impact of delaying pruning three weeks after bud break on eight different cultivar/selections at Industry, Texas.

In conclusion, late pruning had a significant negative impact on cluster number and severity was cultivar dependent. On average late pruning significantly reduced cluster count by approximately 50%, but across cultivars/selections reductions in cluster count ranged from 19-80% possibly as a result of inherent differences in fruitfulness. Although shoot diameter varied by cultivar, the timing of pruning did not negatively impact vine vigor. These results suggest the timing of delayed pruning is important particularly with certain cultivars and pruning too late can be detrimental to grape yield. Further research on the impact of delayed pruning on fruitfulness and yield is warranted.

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